FAR-IR CALIBRATION SOURCES FOR CRYOGENIC FOCAL PLANES

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ABSTRACT

Infrared calibration sources (emitters) have been built using a "reverse bolometer" approach. A NiCr thin film is deposited on a thin sapphire chip, forming a robust, resistive heater with high emissivity. The heater is suspended within a metal ring using nylon fibers, and electrically connected with low thermal conductivity wires. They provide a wide range of greybody output (nominally 10K to 300K) with minimal power dissipation to the cold bath. Under typical operating conditions, a 40K equivalent blackbody output can be obtained with 1 to 2 mW electrical input power. The devices will be used for in-flight array calibration in the Multiband Imaging Photometer for SIRTF (MIPS) and the SPIRE instrument for the Herschel mission.

1. INTRODUCTION AND DEVICE DESIGN

Far-Infrared astronomical and astrophysical observations require highly specialized optics and detector systems. The complexity of these instruments varies, but most generally require carefully controlled cryogenic systems, specialized optical filters, cryogenic actuators, and detector arrays based on bolometers or photoconductors. While all of these systems are carefully engineered to be robust and reliable, changes in one or more components during long-term experiments can severely limit the quality of the observational data. On-board calibration sources are highly desirable for Far-IR instruments.

We have developed a low power, miniature greybody calibration source that can be mounted directly to a cryogenic surface in a Far-IR instrument. As shown in Figure 1, the device is based on a "reverse bolometer" approach. It consists of a 30 to 50 micrometer thick sapphire piece that is suspended on nylon fibers in the middle of a metal ring. The sapphire has been NiCr coated on one surface via RF sputtering, and fine wires of copper or brass, hereafter referred to as "G wires," are attached using silver epoxy[1] to opposing edges of the NiCr film. These are used to pass a current through the NiCr layer and heat the sapphire plate. In some, but not all devices, 50 micrometer wide stripes of Titanium (150 Å thickness) followed by Gold (2000 Å thickness) were deposited on the NiCr film along the current-injecting edges to homogenize the electrical field and reduce current densities at the injection point. During operation the heated sapphire generates photons within a specific Planck Function bandpass that depends on the final temperature of the chip. The wire composition, diameter and length greatly affect the speed and power characteristics of the devices. Careful control of the NiCr film sheet conductivity provides frequency independent emissivity by producing a parallel combination impedance (NiCr film in parallel with free space) that matches the internal impedance of the sapphire. We expect that 50% of our emitter power is internally absorbed and eventually dissipated along the wires, while 50% of the power is transmitted from the emitter surface, creating a greybody source. Further design details are given in reference 2.

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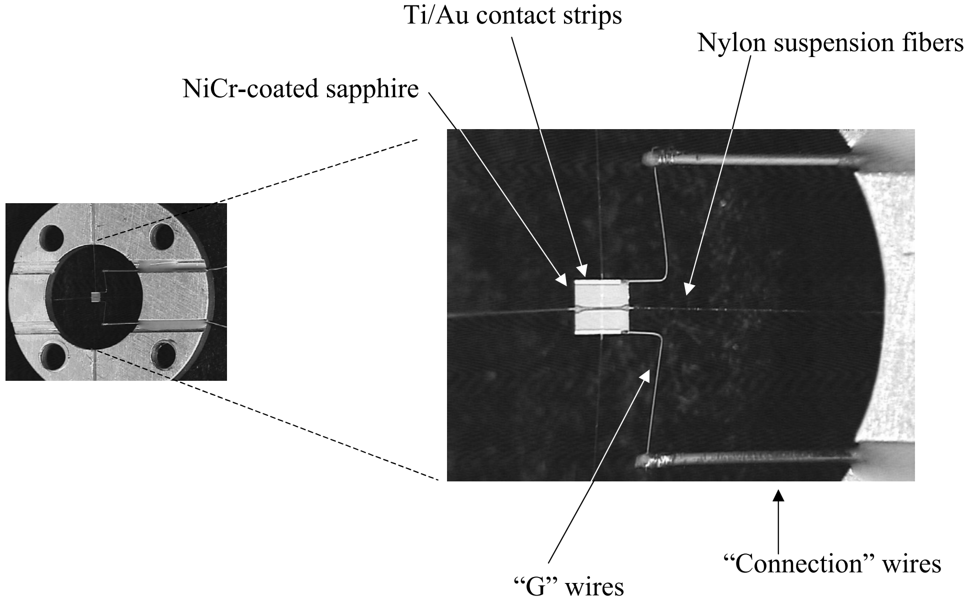

Figure 1. A low power far-IR emitter

2. EXPERIMENTAL SETUP AND RESULTS

A cryogenic test apparatus was built specifically for measuring the performance of emitters, and the details of the design are shown in Figure 2.

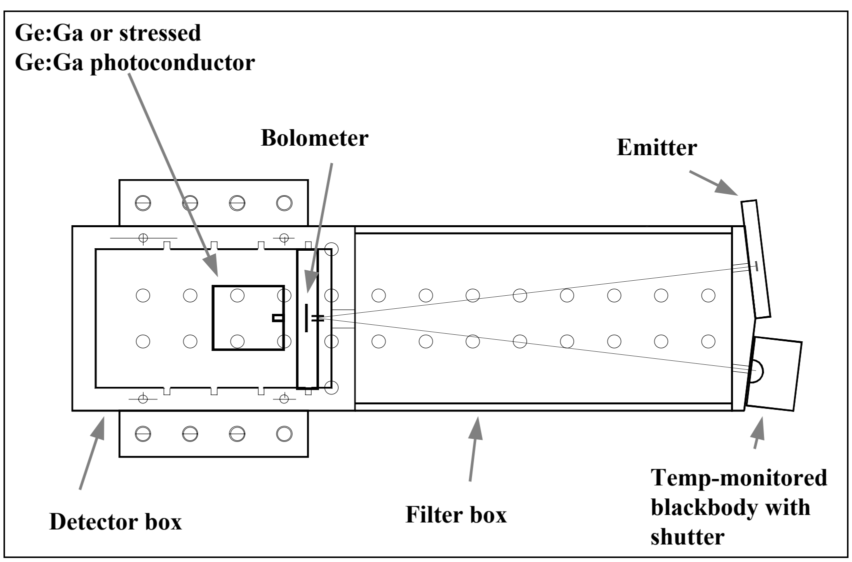

Figure 2. Design details of the emitter test aparatus

This design relies on a "two box" approach. A detector box was designed that is fully light tight except for a front aperture. This defines the field of view for the detector(s) and helps reduce stray light. There are two light-sealed electrical feedthroughs into this box, one for connecting a photoconductor and one for connecting a bolometer. In most tests a bolometer with an open ring structure was used in front of a photoconductor, creating a "coaxial" detector scheme. This approach proved quite useful, since the bolometer was better at measuring the time constant of higher power signals, but was less sensitive to small signals at our typical operating temperatures. The photoconductor (either Ge:Ga or stressed Ge:Ga) detected much smaller signals, even after one pass through the bolometer absorber, but these devices sometimes produce long time constants that affect the quality of the data. The coaxial approach allowed us to choose the best data for each measurement.

Mated to the detector box is a "filter box." This box consists of a shielded, long optical pathway with two equivalent entrance apertures, both located opposite of the detector box aperture. The long pathway ensures that both apertures appear in the detector's field of view, and facillitates the optional placement of filters in the optical path. One of the apertures incorporates a lightweight, fully heat-sunk shutter. The shutter is externally actuated, opens quickly, and produces negligible photon self-emission. A calibrated cryogenic blackbody is mounted behind the shutter. This device consists of a solid copper cylinder with a hemispherical depression at one end. The depression serves as the emission surface of the blackbody and it is coated with Stycast Epoxy,[3] chosen for its high thermal conductivity and high emissivity at long wavelengths. The blackbody is mounted to, but stood off from the cold bath via two 0-80 stainless steel screws, minimizing thermal conduction to the bath. A Lake Shore calibrated Cernox thermistor[4] and a heater resistor (100 ohms, metal film) are both mounted securely to the blackbody, providing temperature monitoring and heating respectively. Test emitters are mounted next to the blackbody, behind the second filter box aperture. To avoid stray light problems, they are sealed on all sides with a combination of mounting brackets and metallic foil tape. During assembly of the test setup, a borescope[5] is used to examine all optical components in-situ, ensuring that all detectors and emission surfaces are centered in their respective apertures, etc.

A variety of emitters were calibrated using the above apparatus. This entailed generating input power vs. "effective temperature" functions, measuring emitter efficiency in terms of power dissipation to the cold bath versus photon power output, time constant determinations, rudimentary emissivity tests and lifetime evaluations. Following these tests, a final device configuration for MIPS was selected. Aluminum support rings and 25 μm diameter brass G wires were chosen. In general, all MIPS devices generate a 40 K "equivalent" blackbody with approximately 0.8 mW power, and the temperature vs applied voltage dependence is linear, providing for easy calibration. In an accelerated lifetime test, one of these devices was cycled 90,000 times over three days between 2 K and 40 K. This device showed a constant output within 0.8% over the three days of testing. After successful cryogenic shake testing at Ball Aerospace, these devices are now considered flight qualified. Further details of these tests may be found elsewhere[2].

3. FUTURE WORK

Throughout the testing phase for the SIRTF devices the emitters proved to be quite robust. One device was inadvertently cycled to 10X it's nominal maximum voltage, and this device survived and still performed well, despite melt-through of the nylon support fibers. Future infrared instruments including SPIRE on board ESA's Herschel telescope are now expected to use similar devices for "in-situ"calibration. Prototype SPIRE emitters are currently built by a private company[6] and these next generation devices will likely be based on a cantilever design as shown in Figure 3.

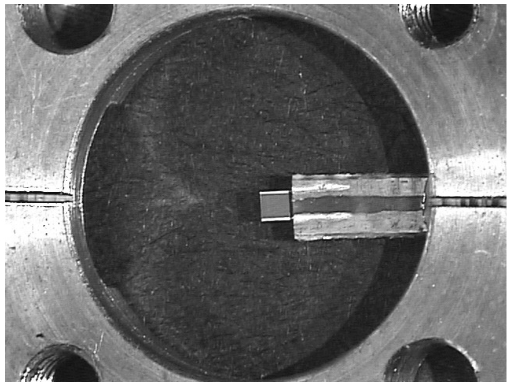

Figure 3. A "Cantilever" Emitter

Using low mass, 6 μm thick mica[7] emission plates, low G wires, and foregoing nylon fiber suspension, these devices prove to be simpler to build and demonstrate faster time constants than the MIPS devices. Typically, a 45K equivalent blackbody is achieved with 1.5 mW of input power (the instrument requirement is < 4 mW). At this operating point, the 90% full value time constant is measured as 220 ms (requirement < 350 ms). A prototype device has been shaken to 40G (sine sweep to 110 Hz) and 18G rms random (80G peak) and has survived with no degradation.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

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